

We Claim:

1. A method of forming a plurality of movable optical traps, the method comprising:

5 generating a focused beam of light;

directing the focused beam of light at a phase patterning optical element having a variable optical surface to form a plurality of beamlets emanating from the phase patterning optical element, each beamlet having a phase profile;

10 converging the beamlets emanating from the phase patterning optical element at a position between the phase patterning optical element and a single transfer lens with the phase patterning optical element;

directing the beamlets emanating from the phase patterning optical element through the single transfer lens to overlap the beamlets at the back aperture of a focusing lens; and

15 converging the beamlets emanating from the focusing lens to form a plurality of optical traps.

2. The method of claim 1 further comprising altering the position of the convergence of at least one beamlet emanating from the phase patterning optical element by varying the optical surface to change the location of at least one optical trap.

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3. The method of claim 1 wherein the optical traps are selected from the group consisting of optical tweezers, optical vortices, optical bottles, optical rotators, light cages, and combinations thereof.

25 4. The method of claim 3 further comprising changing the phase profile of at least one of the beamlets emanating from the phase patterning optical element by varying the optical surface.

30 5. The method of claim 1 further comprising manipulating biological material with the optical traps.

6. The method of claim 1 wherein the focused beam of light is a laser beam.

7. The method of claim 6 wherein the wavelength of the laser beam is in the green spectrum.

5           8. The method of claim 6 wherein the wavelength of the laser beam is selected from the range of about 400 nm to about 1060 nm.

9. The method of claim 1 further comprising steering the beamlets emanating from the phase patterning optical element as a group prior to overlapping the beamlets at the back  
10 aperture of the focusing lens with a movable mirror.

10. A method of forming a plurality of movable optical traps, the method comprising:

generating a focused beam of energy;  
15 directing the focused beam of energy at a phase patterning optical element having a variable optical surface to form a plurality of beamlets;  
converging the beamlets with the phase patterning optical element;  
directing the beamlets through a single transfer lens to overlap the beamlets at the back aperture of a focusing lens; and  
20 converging the beamlets emanating from the focusing lens to a plurality of optical traps.

11. The method of claim 10 further comprising altering the convergence of at least one beamlet emanating from the phase patterning optical element by varying the optical  
25 surface to change the location of at least one optical trap.

12. The method of claim 10 further comprising forming two or more different classes of optical traps selected from the group consisting of optical tweezers, optical vortices, optical bottles, optical rotators, and light cages.

30 13. The method of claim 12 further comprising changing, with the phase patterning optical element, the phase profile of at least one of the beamlets.

14. The method of claim 10 wherein the focused beam of energy is electromagnetic wave energy.

- 5           15. A method of forming and monitoring a plurality of movable optical traps comprising:
- generating a focused beam of light;
  - directing the focused beam of light at a phase patterning optical element to form a plurality of beamlets emanating from the phase patterning optical element having a variable
  - 10   optical surface, each beamlet having a phase profile;
  - converging the beamlets emanating from the phase patterning optical element at a position between the phase patterning optical element and a single transfer lens with the phase patterning optical element;
  - directing the beamlets emanating from the phase patterning optical element through
  - 15   a single transfer lens to overlap the beamlets at a surface of a beam splitter and to create two streams of beamlets, the beam splitter reflecting the first stream of beamlets to the back aperture of a focusing lens and reflecting the second stream of beamlets to form an optical data stream; and
  - converging the beamlets emanating from the focusing lens to form a plurality of
  - 20   optical traps.

16. The method of claim 15 further comprising altering the convergence of at least one beamlet emanating from the phase patterning optical element to change the location of at least one optical trap.

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17. The method of claim 15 further comprising forming two or more different classes of optical traps selected from the group consisting of optical tweezers, optical vortices, optical bottles, optical rotators, and light cages.

30           18. The method of claim 17 further comprising changing, with the phase patterning optical element, the phase profile of at least one of the beamlets.

19. The method of claim 15 further comprising manipulating biological material with the optical traps.

20. The method of claim 15 wherein the focused beam of light is a laser beam.

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21. The method of claim 20 wherein the wavelength of the laser beam is in the green spectrum.

22. The method of claim 20 wherein the wavelength of the single laser beam is selected from the range of about 400 nm to about 1060 nm.

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23. The method of claim 15 further comprising steering the beamlets emanating from the phase patterning optical element as a group prior to overlapping the beamlets at the back aperture of the focusing lens with a movable mirror.

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24. The method of claim 15 further comprising converting the optical data-stream to a video signal.

25. The method of claim 15 further comprising obtaining and then analyzing the spectrum of the optical data-stream.

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26. The method of claim 15 further comprising receiving the optical data-stream with a computer.

27. The method of claim 16 wherein the varying of the optical surface is directed with a computer.

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28. The method of claim 25 further comprising varying the optical surface to change the location of at least one optical trap in response to the analyzed spectrum of the optical data stream.

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29. The method of claim 24 further comprising varying the optical surface to change the location of at least one optical trap in response to the video signal.

30. The method of claim 15 further comprising filtering out all but a preselected  
5 wavelength of light from the optical data stream.

31. The method of claim 15 further comprising filtering out one or more preselected wavelengths of light from the optical data stream.

10 32. The method of claim 15 further comprising selectively generating the focused beam of light and selectively blocking and unblocking the optical data-stream, so that when the focused beam of light is not being generated, the optical data stream is blocked and when focused beam of light is being generated, the optical data stream is unblocked.

15 33. The method of claim 15 further comprising:  
selectively blocking and unblocking the beamlets emanating from the phase patterning optical element from passing to the beam splitter; and  
selectively monitoring the optical data-stream when blocking the beamlets.

20 34. An apparatus to produce at least two optical traps comprising:  
a phase patterning optical element for receiving a focused beam of light and diffracting it into at least two beamlets, each beamlet having a phase profile;  
a virtual lens encoded in the phase patterning optical element for converging each beamlet emanating from the phase patterning optical element at a position between the  
25 phase patterning optical element and a single transfer lens;  
the single transfer lens for directing the beamlets emanating from the phase patterning optical element to overlap the beamlets at the back aperture of a focusing lens;  
the focusing lens for converging each beamlet emanating from the transfer lens to form the optical traps; and  
30 a single transfer lens between the phase patterning optical element and the focusing lens which overlaps the beamlets at the back aperture of the focusing lens.

35. The apparatus of claim 34 wherein the single transfer lens is movable.

36. The apparatus of claim 34 wherein the phase patterning optical element has a static surface.

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37. The apparatus of claim 36 wherein the static surface is repositionable to align different portions of the static surface to receive the beam of light.

38. The apparatus of claim 37 wherein the static surface is comprised of two or more discrete non-homogeneous regions.

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39. The apparatus of claim 37 wherein the static surface is substantially continuously varying.

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40. The apparatus of claim 36 wherein the phase patterning optical element is selected from at least one of the group consisting of gratings, diffraction gratings, reflective gratings, transmissive gratings, holograms, stencils, light shaping holographic filters, polychromatic holograms, lenses, mirrors, prisms, waveplates, and holograms.

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41. The apparatus of claim 34 wherein the phase patterning optical element is dynamic.

42. The apparatus of claim 41 wherein selectively varying the encoded virtual lens changes the number of beamlets emanating therefrom.

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43. The apparatus of claim 41 wherein selectively varying the encoded virtual lens changes the position of the convergence of at least one of the beamlets emanating therefrom.

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44. The apparatus of claim 41 wherein selectively varying the phase patterning optical element changes the phase profile of at least one of the beamlets emanating therefrom.

45. An apparatus to produce and monitor at least two optical traps comprising:  
a phase patterning optical element for receiving a focused beam of light and  
diffracting it into at least two beamlets, each beamlet having a phase profile;

5 a virtual lens encoded in the phase patterning optical element for converging each  
beamlet emanating from the phase patterning optical element at a position between the  
phase patterning optical element and a single transfer lens;

the single transfer lens for directing the beamlets emanating from the phase  
patterning optical element to overlap at a surface of a beam splitter;

10 the beam splitter for receiving the beamlets emanating from the single transfer lens  
to create two streams of beamlets, then to reflect the first stream of beamlets to the back  
aperture of a focusing lens and reflect the second stream of beamlets to form an optical data  
stream; and

the focusing lens for converging each beamlet emanating from the beam splitter to  
15 form at least two optical traps.

46. The apparatus of claim 45 wherein the single transfer lens is movable.

47. The apparatus of claim 45 wherein the phase patterning optical element has a  
20 static surface.

48. The apparatus of claim 47 wherein the static surface is repositionable to align  
different portions of the static surface to receive the beam of light.

25 49. The apparatus of claim 48 wherein the static surface is comprised of two or  
more discreet non-homogeneous regions.

50. The apparatus of claim 48 wherein the static surface is substantially  
continuously varying.

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51. The apparatus of claim 47 wherein the phase patterning optical element is  
selected from at least one of the group consisting of gratings, diffraction gratings, reflective

gratings, transmissive gratings, holograms, stencils, light shaping holographic filters, polychromatic holograms, lenses, mirrors, prisms, waveplates, and holograms.

52. The apparatus of claim 45 wherein the phase patterning optical element is  
5 dynamic.

53. The apparatus of claim 52 wherein the dynamic phase patterning optical  
element is selectively variable whereby the number of beamlets emanating therefrom can be  
changed.

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54. The apparatus of claim 52 wherein the dynamic phase patterning optical  
element is selectively variable whereby the position of the convergence of each separate  
beamlet emanating therefrom can be changed.

55. The apparatus of claim 52 wherein the dynamic phase patterning optical  
element can be selectively varied whereby the phase profile of each separate beamlets  
emanating therefrom can be changed.

56. The apparatus of claim 52 wherein the phase patterning optical element is  
20 selected from at least one of the group consisting of variable computer generated diffractive  
patterns, variable phase shifting materials, variable liquid crystal phase shifting arrays,  
micro-mirror arrays, piston mode micro-mirror arrays, spatial light modulators, electro-optic  
deflectors, accousto-optic modulators, deformable mirrors and reflective MEMS arrays.

57. The apparatus of claim 45 wherein the beam splitter is selected from at least one  
25 of the group consisting of stationary omnidirectional mirrors, stationary photonic band gap  
mirrors, stationary dichroic mirrors, movable omnidirectional mirrors, movable photonic  
band gap mirrors and movable dichroic mirrors.

58. The apparatus of claim 45 further comprising a movable mirror disposed  
30 upstream of the transfer lens for steering the beamlets emanating from the phase patterning

optical element as a group prior to overlapping the beamlets at the back aperture of the focusing lens.

5 59. The apparatus of claim 58 further comprising a telescope lens system between the movable mirror and the focusing lens.

60. An apparatus to produce and monitor a plurality of optical traps comprising:  
a dynamic diffractive optical element for receiving a single laser beam and  
diffracting it into at least two beamlets, each beamlet having a phase profile;  
10 a virtual lens encoded in the diffractive optical element for converging the beamlets emanating from the phase patterning optical element at a position between the phase patterning optical element and a single transfer lens;  
the single transfer lens for directing the beamlets emanating from the phase patterning optical element to overlap at a surface of a beam splitter;  
15 the beam splitter for receiving the beamlets emanating from the single transfer lens to create two streams of beamlets, then to reflect the first stream of beamlets to the back aperture of a focusing lens and reflect the second stream of beamlets to form an optical data stream; and  
the focusing lens for converging each beamlet emanating from the beam splitter to  
20 form at least two optical traps.

61. A system to produce a plurality of optical traps for manipulating small particles comprising:  
a plurality of small particles;  
25 a light source for producing a focused beam of light;  
a focused beam of light;  
a phase patterning optical element for receiving the focused beam of light and diffracting it into at least two beamlets, each beamlet having a phase profile;  
a virtual lens encoded in the phase patterning optical element for converging each  
30 beamlet emanating from the phase patterning optical element at a position between the phase patterning optical element and a single transfer lens;

the single transfer lens disposed between the phase patterning optical element and a focusing lens through which each beamlet passes and is overlapped at the back aperture of the focusing lens; and

the focusing lens for converging each beamlet emanating from the transfer lens to  
5 form at least two optical traps each able to manipulate one of the plurality of small particles.

62. The system of claim 61 wherein the single transfer lens is movable.

63. The system of claim 61 wherein the optical traps move corresponding to the  
10 movement of the single transfer lens.

64. The system of claim 64 wherein the phase patterning optical element has a variable optical surface.

65. The system of claim 66 wherein the phase patterning optical element has a  
15 static surface.

66. The system of claim 67 wherein the static surface is movable to selectively  
align the focused beam of light with a selected area of the static surface.  
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67. The system of claim 67 wherein the static surface is comprised of two or more discreet non-homogeneous regions.

68. The system of claim 67 wherein the static surface is substantially continuously  
25 varying.

69. The system of claim 67 wherein the phase patterning optical element is selected from at least one of the group consisting of gratings, diffraction gratings, reflective gratings, transmissive gratings, holograms, stencils, light shaping holographic filters,  
30 polychromatic holograms, lenses, mirrors, prisms, waveplates, and holograms.

70. The system of claim 61 wherein the phase patterning optical element is dynamic.

71. The system of claim 72 wherein the phase patterning optical element is  
5 selected from at least one of the group consisting of variable computer generated diffractive patterns, variable phase shifting materials, variable liquid crystal phase shifting arrays, micro-mirror arrays, piston mode micro-mirror arrays, spatial light modulators, electro-optic deflectors, accousto-optic modulators, deformable mirrors and reflective MEMS arrays.

10 72. The system of claim 72 further comprising a computer to selectively vary the phase patterning optical element.

73. The system of claim 61 wherein at least some of the plurality of small particles  
15 are a biological material.

74. The system of claim 61 wherein the light source is a laser and the focused beam of light is a laser beam with a wavelength in the green spectrum.

75. The system of claim 61 wherein the light source is a laser and the focused  
20 beam of light is a laser beam with a wavelength selected from the range of about 400 nm to about 1060 nm.

76. The system of claim 61 further comprising a movable mirror to steer the beamlets emanating from the phase patterning optical element as a group prior to  
25 overlapping the beamlets at the back aperture of the focusing lens.

77. The system of claim 61 further comprising a telescope lens system downstream from the single lens and before the focusing lens.

30 78. A system for manipulating small particles using optical traps comprising:  
a plurality of small particles;  
a light source for producing a focused beam of light;

- a focused beam of light;
- a phase patterning optical element which receives the focused beam of light and diffracts it into at least two beamlets, each beamlet having a phase profile;
- a virtual lens encoded in the phase patterning optical element which converges each
- 5 beamlet emanating from the phase patterning optical element at a position between the phase patterning optical element and a single transfer lens;
- a beam splitter for receiving the beamlets emanating from the phase patterning optical element and creating two streams of beamlets and for reflecting the first stream of beamlets to overlap the back aperture of a focusing lens and reflecting the second stream of
- 10 beamlets to form an optical data stream;
- the single transfer lens disposed between the phase patterning optical element and the focusing lens through which each beamlet passes and is overlapped at the back aperture of the focusing lens;
- at least two optical traps each able to manipulate one of the plurality of small
- 15 particles; and
- a monitor for the optical data stream.

79. The system of claim 80 wherein the single transfer lens is movable.

- 20 80. The system of claim 81 wherein the optical traps move corresponding to the movement of the single transfer lens.

81. The system of claim 83 wherein the phase patterning optical element has a variable optical surface.

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82. The system of claim 85 wherein the phase patterning optical element has a static surface.

83. The system of claim 86 wherein the static surface is movable to selectively
- 30 align the focused beam of light with a selected area of the static surface.

84. The system of claim 86 wherein the static surface is comprised of two or more discreet non-homogeneous regions.

85. The system of claim 86 wherein the static surface is substantially continuously  
5 varying.

86. The system of claim 86 wherein the phase patterning optical element is selected from at least one of the group consisting of gratings, diffraction gratings, reflective gratings, transmissive gratings, holograms, stencils, light shaping holographic filters,  
10 polychromatic holograms, lenses, mirrors, prisms, waveplates, and holograms.

87. The system of claim 85 wherein the phase patterning optical element is dynamic.

88. The system of claim 91 wherein the phase patterning optical element is selected from at least one of the group consisting of variable computer generated diffractive patterns, variable phase shifting materials, variable liquid crystal phase shifting arrays, micro-mirror arrays, piston mode micro-mirror arrays, spatial light modulators, electro-optic deflectors, accousto-optic modulators, deformable mirrors and reflective MEMS arrays.  
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89. The system of claim 91 further comprising a computer to selectively control the dynamic phase patterning optical element.

90. The system of claim 80 wherein at least some of the plurality of small particles  
25 are biological material.

91. The system of claim 80 wherein the light source is a laser and the focused beam of light is a laser beam with a wavelength in the green spectrum.

92. The system of claim 80 wherein the light source is a laser and the focused  
30 beam of light is a laser beam with a wavelength selected from the range of about 400 nm to about 1060 nm.

93. The system of claim 80 further comprising a movable mirror to steer the beamlets emanating from the phase patterning optical element as a group prior to overlapping the beamlets at the back aperture of the focusing lens.

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94. The system of claim 80 further comprising a telescope lens system downstream from the single lens and before the focusing lens.

95. The system of claim 80 wherein the monitor is a human monitor.

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96. The system of claim 80 wherein the monitor is a video monitor.

97. The system of claim 80 further comprising converting the optical data-stream to a digital data-stream.

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98. The system of claim 80 further comprising a spectrometer for producing a spectrum of the optical data-stream.

99. The system of claim 80 further comprising a computer for receiving a digital data stream obtained by converting the optical data-stream to a digital data stream.

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100. The system of claim 80 further comprising a computer for receiving the optical data stream and processing it into a digital data stream and for changing the location of at least one of the optical traps based on the information in the optical data-stream.

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101. The system of claim 104 further comprising a computer for directing a movable mirror to steer the beamlets emanating from the phase patterning optical element as a group prior to overlapping the beamlets at the back aperture of the focusing lens.

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102. The system of claim 102 further comprising:  
a computer for analyzing the spectrum; and

a computer for directing a movable mirror to steer the beamlets emanating from the phase patterning optical element as a group prior to overlapping the beamlets at the back aperture of the focusing lens.

5           103. The system of claim 80 further comprising a polarizing filter or a band pass filter placed within the pathway of the optical data-stream.

10           104. The system of claim 80 further comprising a shutter to selectively block the optical data-stream while the focused beam of light is on and unblock the optical data-stream when the focused beam of light is off.

          105. The system of claim 80 further comprising a shutter to selectively block the focused beam of light when the optical data-stream is being monitored.

15           106. The system of claim 80 wherein the source for producing a focused beam of light is a laser and the focused beam of light is a laser beam.

          107. The system of claim 110 further comprising:  
          a first shutter to selectively block the laser beam when the optical data-stream is  
20   being monitored; and  
          a second shutter to selectively block the optical data-stream while the laser beam is on and unblock the optical data-stream when the laser beam is off.

25           108. An optical system for monitoring and manipulating small particles comprising:

          a source of a single beam of focused energy;  
          a single beam of focused energy;  
          a dynamic diffractive optical element;  
          a plurality of converged beamlets produced by directing the single beam at the  
30   optical element;  
          a focusing lens;

a beam splitter placed in the path of the converged beamlets creating two streams of beamlets and reflecting the first stream of beamlets to overlap the back aperture of the focusing lens and reflecting the second stream of beamlets to form an optical data stream;

a movable single lens disposed between the optical element and the beam splitter to  
5 direct that beamlets to the beam splitter;

at least two optical traps formed by the convergence of the beamlets through the focusing lens; and

a monitor for the optical data stream.

10 109. The system of claim 112 wherein the source of a single beam of focused energy is selected from the group consisting of solid state lasers, diode pumped lasers, gas lasers, dye lasers, alexanderite lasers, free electron lasers, VCSEL lasers, diode lasers, Ti-Sapphire lasers, doped YAG lasers, doped YLF lasers, diode pumped YAG lasers, flash lamp-pumped YAG lasers, light emitting diodes, and light emitting diodes with integrated  
15 collimating elements.

110. The system of claim 112 wherein the focused beam of light is electromagnetic energy.

20 111. The system of claim 112 wherein the optical traps move corresponding to the movement of the single lens.

112. The system of claim 112 wherein a change in the location of an optical trap results from at least one change in the optical element.

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113. The system of claim 114 wherein each optical trap is selected from the group consisting of optical tweezers, optical vortices, optical bottles, optical rotators and light cages.

30 114. The system of claim 61 wherein each optical trap is selected from the group consisting of optical tweezers, optical vortices, optical bottles, optical rotators and light cages.

115. The system of claim 80 wherein each optical trap is selected from the group consisting of optical tweezers, optical vortices, optical bottles, optical rotators and light cages.

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116. A method of forming a plurality of movable optical traps, the method comprising:

generating a focused beam of light;

10 directing the focused beam of light at a phase patterning optical to form a plurality of beamlets emanating from the phase patterning optical element, each beamlet having a phase profile;

converging the beamlets emanating from the phase patterning optical element at a position between the phase patterning optical element and a single transfer lens with the phase patterning optical element;

15 directing the beamlets emanating from the phase patterning optical element with a movable mirror through the single transfer lens to overlap the beamlets at the back aperture of a focusing lens; and

converging the beamlets emanating from the focusing lens to form a plurality of optical traps.

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117. The method of claim 120 further comprising moving the mirror to change the location of at least one optical trap.

25 118. The method of claim 120 wherein the optical traps are selected from the group consisting of optical tweezers, optical vortices, optical bottles, optical rotators, light cages, and combinations thereof.

119. The method of claim 120 further comprising manipulating biological material with the optical traps.

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